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GEOTHERMAL POWER PRODUCTION: ACCIDENTAL FLUID RELEASES, WASTE DISPOSAL, AND WATER USE

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GEOTHERMAL POWER PRODUCTION: ACCIDENTAL FLUID RELEASES, WASTE DISPOSAL, AND WATER USE

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Abstract

Environmental problems related to the use and disposal of fluids can accompany the operation of geothermal power plants using hot water resources (temperatures >150°C). More than 100 kg of fluids must be extracted, processed, and disposed for each kW·h of electricity generated from a facility relying on a geothermal reservoir with fluids of 150°C. The low thermal efficiencies of geothermal power plants result in large requirements for cooling water--over 7.4 x 10^4 m^3/MW·yr compared with 1.7 x 10^4 m^3/MW·yr for coal-fired plants. Geothermal fluids can contain as much as 250,000 mg/l total dissolved solids. Toxic substances like boron and NH_3 are often present in fluids. This paper focuses on impacts associated with accidental releases of geothermal fluids as well as the disposal of liquid and solid wastes. The consequences of consuming alternative sources of cooling water are also addressed. Inadvertent discharges of fluids are of concern because they could contaminate soils and surface waters, adversely affecting crops and aquatic organisms. The pretreatment of fluids before subsurface injection could lead to solid waste problems--especially when toxic substances are produced. The consumption of alternative cooling waters can pose problems involving the disposal of blowdown from cooling towers. In

addition, the toxicity of drift emitted from cooling towers depends on the kind of cooling water used.

INTRODUCTION

The energy potential of the known hot-water geothermal resources in the United States is estimated to be equivalent to 21,000 MW generated for 30 years(1). The energy potential of undiscovered resources could add considerably to that estimate. Hot-water resources, nevertheless, are just beginning to be developed for electric power generation. Some of the initial geothermal facilities using these resources will be installed in the Imperial Valley of California, where almost a third of the nation's identified, hot-water resources are located. For geothermal development to proceed unhindered in the valley, power plants must be operated in a manner that is environmentally acceptable. Therefore, it is important to carefully assess the impacts of geothermal operations before development to define potential environmental problems and to determine ways of resolving them.

Geothermal energy production in the Imperial Valley could result in environmental impacts that are similar to those that have already appeared at The Geysers dry-steam resource area in northern California. At The Geysers, where electricity has been commercially generated for about 20 years, negative impacts have been caused by the deposition of cooling-tower drift on vegetation and emissions of H_2S(2). As a consequence, control technologies have been implemented to minimize such releases.

Geothermal power plants in the valley that have a flashed-steam design are likely to have the same kinds of pollutant releases, and controls may also be necessary to prevent negative impacts.

A special concern associated with the utilization of hot-water geothermal resources is the inadvertent release of geothermal fluids that contain elevated levels of toxic substances. Because the Imperial Valley is dominated by irrigated agriculture, spills could result in damage to crops and the contamination of soils. The use of alternative sources of cooling water to support geothermal operations may result in additional impacts. For example, emissions of drift from cooling towers could affect crops grown near power plants. The chemistry of the cooling waters used in towers will determine the chemical composition of the drift emitted and, hence, its potential toxicity. Based on experience at The Geysers, we believe that boron contained in drift derived from steam condensate could be a problem. Waste water from cooling towers (i.e., blowdown) discharged to surface waters could be harmful to aquatic organisms if it contains toxic substances like ammonia. The safe disposal of solid and liquid wastes (e.g., drilling muds and residual geothermal fluids) will become an increasingly important consideration, especially as regulations are promulgated under the Resource Conservation and Recovery Act and the Safe Drinking Water Act.

In this paper we will examine some of the important waste

technologies have been implemented to minimize such releases.

defining the need for environmental controls. We will also recommend post-operational studies that would provide relevant data for subsequent evaluations of environmental controls.

GEOTHERMAL RESOURCES AND TECHNOLOGIES

The quantity and quality of waste by-products from power production will vary according to: (a) the physical and chemical properties of geothermal fluids and cooling waters and (b) the types of power plants implemented and their conversion efficiencies. The Imperial Valley has five identified geothermal resource areas (i.e., Salton Sea, Brawley, Heber, East Mesa, and Westmorland), having a total energy potential estimated to be nearly 7,000 MW for 30 years(1). The geothermal fluids associated with the resource areas display a great deal of variation in both temperature and chemical composition(3,4).

As shown in Table 1, the Salton Sea resource area has the highest energy potential and the hottest geothermal fluids. However, it also has the most saline fluids, averaging almost 250,000 mg/l of total dissolved solids (TDS). These fluids have high concentrations of toxic substances such as B, As, and Pb. The least saline fluids are in the East Mesa resource area, which is approximately 60 km to the southeast of the Salton Sea area. The fluids there are about 170^{o}C, and they range from approximately 2,000 mg/l TDS in most wells to over 25,000 mg/l in one

TABLE 1. CHARACTERISTICS OF THE MAJOR GEOTHERMAL RESOURCE AREAS IN THE IMPERIAL VALLEY (1, 5, 6).

Resource area	Energy potential (MW for 30 yr)	Fluid temperature (^{o}C)	Total dissolved solids (mg/l)
Salton Sea	3,400	290	240,000
Westmorland	1,700	215	37,000
Brawley	640	260	76,000
Heber	650	180	14,000
East Mesa	360	170	7,600

well(3,4). The geothermal fluids in that resource area have the lowest concentrations of dissolved substances. In addition to dissolved solids, geothermal fluids contain dissolved gases such as CO_2, H_2S, and NH_3. At ambient temperatures and pressures, these gases are noncondensable. Hydrogen sulfide is present in relatively small concentrations, averaging 3.2 mg/kg of fluid in the Salton Sea area compared to CO_2 at 1700 mg/kg of fluid. Nevertheless, it is the most important gas from an environmental perspective because half the population can detect its odor at concentrations from 0.003 to 0.009 ppm(7).

The amount of waste by-products resulting from power generation will depend not only on the chemical composition of geothermal fluids, but also on the quantity of fluids that are processed to produce a kW·h of electricity and the kinds of energy technologies implemented. The fluid requirements of a power plant are essentially a function of the temperature of the extracted fluids. As the temperature of geothermal fluids increases, the conversion efficiency of a plant also increases, thereby reducing the demand for fluids. A 50-MW power plant relying on resources at about $170^{\circ}C$ would require as much as 6.5×10^6 kg fluids/h. The same size plant using fluids at $275^{\circ}C$ would require about 2.0×10^6 kg fluids/h.

In a flashed-steam cycle, electricity is generated by running a turbogenerator on steam that has been separated from hot fluids extracted from a geothermal reservoir. In the basic binary-fluid cycle, geothermal fluids are kept under pressure, and heat exchangers are used to transfer the heat of the geothermal fluids to an organic working fluid that is vaporized and sent through a turbogenerator. Flashed-steam facilities emit noncondensable gases such as hydrogen sulfide, but they can use steam condensate as a source of cooling water. Binary plants, in contrast, are not expected to have significant emissions of gases because geothermal fluids are pressurized. However, these facilities must rely on external sources of water for cooling. Both types of power plants must dispose of waste fluids by subsurface injection.

ACCIDENTAL FLUID RELEASES

Until some experience has been gained in the extraction, processing, and disposal of large quantities of fluids for actual power plants, frequency and magnitude of accidental fluid releases will be difficult to predict. Nevertheless, accidental spills are plausible events, and, therefore, the consequences of this type of release should be assessed to define possible controls and mitigation measures.

An inadvertent release of geothermal fluids would amount to 1,300 m^3 if, for example, the entire fluid flow of a 50-MW power plant processing 30 m^3/min were spilled for nearly 45 min before it could be stopped. A spill of that magnitude could come into contact with crops because some geothermal facilities will undoubtedly be sited next to irrigated lands in the valley. During a spill onto cultivated land, the heat of the geothermal fluids could destroy crops. Longer term impacts on soils and future plantings of crops would result from the contamination of soils and soil waters. To examine what happens when geothermal fluids mix with soil waters after percolation, Sposito et al.(8) used a computerized model, GEOCHEM, to calculate the speciation of trace metals in mixtures of representative fluids and soil waters. They found that sulfides present in geothermal fluids and the exchange surfaces in soils can remove trace metals such as Ni, Cu, Zn, and Pb, which can be toxic to crops. They also found that Li and B do not easily precipitate. As a result, these substances could reach harmful levels in soil waters if enough geothermal fluids percolate into soils during a spill.

Inadvertent releases also have the potential of contaminating surface waters, particularly the water in drainage ditches that criss-cross the valley's farmlands to remove agricultural waste waters. The severity of a spill would depend on the chemical composition of the geothermal fluids released and the drain waters they enter, the quantity of fluid reaching a drain, and the drain's flow rate. The effect of a spill would be severest near the entrance of fluids into the drain. A spill would have a transient impact on water quality because of the movement of water in the drain. Elevated salinity resulting from the discharge of saline water into a drain could increase osmotic stress to fish. Furthermore, precipitates reaching bottom sediments could become a source of toxic substances in the food chain.

Harmful releases of toxic fluids--especially from future facilities in the Brawley and Salton Sea resource areas--can be avoided in a couple of ways. The simplest method is to construct containment berms around places where spills are most likely, such as the areas immediately around production and injection wells and power plants. To reduce the amount of an inadvertent release, pressure-activated alarms could be installed to alert plant operators of a spill(9). The use of alarms would reduce the magnitude of spills, assuming that remedial actions could be undertaken in a timely fashion.

If a spill should reach a cultivated field, the affected land may be reclaimed by leaching. Nearly all of the fields in the valley already have subsurface drain lines that are used to remove saline waters from the root zones of crops. Extra water must be applied to irrigated lands to leach excess salts through the soil column. Without subsurface drainage, soil salinities would rise, reducing the yield of crops. Jury and Weeks(10) studied the use of leaching to remove toxic substances from soils. Their analyses indicate that full ponding of contaminated soils is the best method of leaching. However, they concluded that only spills that affected soils in the immediate vicinity of a subsurface drain line could be reclaimed over a period of weeks or even months. New drains would have to be installed to facilitate the leaching of contaminated soils that are distant from existing subsurface drains.

WASTES FROM GEOTHERMAL OPERATIONS

Liquid and solid wastes generated during various geothermal operations in the Imperial Valley pose major disposal problems. Figure 1 illustrates the principal waste-producing sources, the types of wastes involved, and the options available for their disposal. Spent geothermal fluids represent the most abundant form of waste associated with geothermal power production in the valley. This is a direct consequence of the relatively large fluid flow rates required by power plants. Conventional disposal methods such as ponding, and evaporation or discharge to surface waters cannot be applied because of the extraordinary land needs for ponding and regulations prohibiting the discharge of geothermal fluids to surface waters. Underground-injection technology seems to be the only feasible disposal option for residual geothermal fluids. In fact, it is probably the most essential environmental control technology for geothermal facilities in the Imperial Valley. Injection not only disposes of large volumes of liquid waste, but it can also help to maintain pressures within a geothermal reservoir. The maintenance of reservoir pressures can alleviate subsurface compaction and associated land subsidence.

A variety of solid wastes are produced from geothermal operations. Wastes result from the preinjection treatment of injection fluids, the removal of scale from pipelines and other components of power plants, and the abatement of H_2S. Some of the wastes produced may be reclaimed through the use of mineral-recovery procedures. However, a large proportion of the solid wastes will require disposal in carefully constructed and monitored land-fill sites. Efforts have been underway in the Imperial Valley to construct at least one disposal site that would be able to receive wastes containing toxic substances. This is an important step in preparing for the commercial development of the valley's geothermal resources. In this section we estimate the quantities of wastes that could be produced with geothermal operations. Special emphasis is placed on the wastes associated with the development of the Salton Sea resource area, which has the highest energy potential but also the greatest waste-disposal problems.

For subsurface injection of spent geothermal fluids to be successful, suspended solids that could plug an injection well or receiving aquifer must be separated from spent fluids. Solids are formed when constituents that were barely soluble at the higher reservoir temperatures are precipitated as the geothermal fluids are cooled in the energy conversion process(11). Methodologies for separating solids before injection have been investigated for some time(12), but a proven process has not yet been found. One promising way to remove solids is to use reaction-clarification coupled with granular media filtration(13,14). In this approach, solids are precipitated in a reactor by a seeding process. A clarification unit is then used to separate solids. The final stage of treatment is the filtration of solids that remain in the injection fluid. Test data for this type of system suggest that it would be possible to remove as much as 95% of the suspended solids from geothermal brines(14). Assuming that this separation efficiency can be achieved in commercial applications, we estimate that solids would be removed at rates of up to 12 kg/MW·h for spent brines in the Salton Sea resource area with 400 mg/l of suspended material. On an annual basis, a 50-MW power plant operating at a 0.75 capacity factor would produce 3.9×10^6 kg of solids.

The control of scale in pipelines and power plant components is another source of solid waste from geothermal operations. Scale deposition depends on the chemical composition of geothermal fluids as well as the physical conditions within pipes (i.e., temperature, pressure, flow rates, and turbulence). Cooling of fluids is a major factor in the deposition of scale. Consequently, most of the scale will be deposited in the cooler locations, such as the pipelines leading to injection wells. As scale builds up, it must be removed periodically and then disposed. Even though scale would constitute only a small fraction of the total mass of fluid that passes through a power plant, it could be significant from a disposal standpoint as it accumulates over time.

Scaling rates have been studied using a geothermal brine flowing at wellhead conditions through a tapered expansion tube equipped with thermocouples to monitor temperature(11). Temperatures were measured at equally spaced intervals along the length of the tube during flow experiments. After the completion of a flow run, scale thickness was measured at each cross-section where the thermocouples were stationed. Scaling rates were calculated to be 26 to 348 μm/h in response to a temperature change from 200°C at the inlet of the 70-cm expansion tube to 100°C at its exit. The mass deposition rate per unit cross-section per unit of time (i.e., g/cm·h) ranged from 1.2 to less than 0.1 g/cm·h at temperatures of approximately 100 to 200°C.

These experimental measurements do not necessarily indicate the scaling that would occur in an actual power plant. The expansion-tube experiment was operated at a flow rate far below that expected in a power plant. Not only will higher rates of flow occur, but also greatly different turbulence conditions are likely to prevail. With these qualifications in mind, we used the experimental data on the scale measurements along with the brine flow rates to calculate a scale-deposition rate of 0.014% of the brine flow at a temperature of 110^{o}C. At that rate of deposition, a power plant using fluids from the Salton Sea resource area would produce almost 6 kg scale/MW·h. A 50-MW facility would produce approximately 2.0×10^6 kg of scale annually. However, recent experimental work with scale inhibitors(15) shows that scale can be reduced at temperatures between 90 and 125^{o}C by using organic additives.

The abatement of H_2S will also result in wastes. Several candidate control technologies exist for removing this gas from geothermal fluids. To estimate the potential magnitude of wastes associated with the abatement of H_2S, we chose the process developed by the EIC Corporation as a practical example. In this process, H_2S present in steam is reacted with a solution of $CuSO_4$ to form insoluble CuS. The insoluble sulfides are then separated and oxidized to $CuSO_4$, which is then recirculated in the control process. Sulfuric acid that is generated during the oxidation of $CuSO_4$ is reacted with an ammonia solution to form ammonium sulfate(16). Testing of the process at The Geysers showed that the residual ammonium sulfate is in direct proportion to the amount of

H_2S present in the process stream. Initial testing demonstrated the feasibility of removing between 95 and 98% of the H_2S in steam(16). The average H_2S concentration of fluids in the Salton Sea resource area was measured at 3.2 mg/kg vs 0.54 mg/kg for fluids at East Mesa. With 95% control of hydrogen sulfide, a 50-MW power plant located in the East Mesa resource area would produce approximately 1.0×10^5 kg of ammonium sulfate per year; the equivalent facility in the Salton Sea area would produce 1.6×10^5 kg/yr. Ammonium sulfate could be used as a fertilizer on agricultural lands in the valley if it did not contain contaminants like boric acid. Otherwise, the ammonium sulfate would have to be transported to a secure land disposal site.

WASTES DERIVED FROM COOLING WATERS

Geothermal energy conversion using hot-water resources is one of the most water-intensive energy technologies known. Besides the large amounts of hot water that must be extracted from a geothermal reservoir to support a generating facility, significant amounts of water are also needed to cool power plants. For example, geothermal facilities can be expected to consume between 7 and 11 m^3 of water per MW·h just to replace evaporative losses from cooling towers. Additional water would be needed to replace discharges of blowdown. Conventional fossil-fueled power plants, in comparison, would consume only around 2 m^3/MW·h to replace both evaporative losses and discharges of blowdown. The lower water requirements of the fossil-fueled plants are a result of their higher conversion efficiencies.

The principal sources of cooling water that could be used to support geothermal facilities in the Imperial Valley consist of irrigation water imported from the Colorado River, waste waters discharged from agricultural lands, and steam condensate from flashed-steam power plants. From an environmental standpoint, irrigation water is the most attractive water supply. The concentrating effect of evaporation in a cooling tower could be controlled so that dissolved substances in the irrigation water circulating in the cooling system would not reach levels that would pose problems associated with emissions of drift or discharges of blowdown to surface waters. Nevertheless, this source of water is already dedicated to agricultural users, and only limited quantities are likely to be available in the future(17).

Agricultural waste waters, on the other hand, amount to about 1.23 x 10^9 m^3 annually(17) and thus represent an important source of cooling water, particularly for binary power plants, which rely on external sources of cooling water. Agricultural effluents contain about 4,000 mg/l TDS and up to

200 mg/l of suspended solids. The most important wastes associated with the operation of cooling towers using agricultural effluents are solids derived from the treatment of makeup water and discharges of saline blowdown.

Suspended material (e.g., sediments and organic matter) must be removed from agricultural waste water before its use in a cooling tower. Otherwise solids could rapidly accumulate as sludge in the basin of a tower. A 50-MW geothermal power plant using high temperature fluids, such as those found in the Salton Sea resource area, would require about 440 m^3/h of agricultural waste water to replace evaporative losses of 350 m^3/h and blowdown discharges of 90 m^3/h, based on five cycles of concentration. To reduce the suspended solids concentration in agricultural effluents from 200 to 50 mg/l, we estimate that approximately 4.4×10^5 kg would have to be separated each year, assuming a plant capacity factor of 0.75. For a similar power plant relying on lower temperature geothermal resource, the amount of solids separated annually could be as much as 6.5×10^5 kg because of higher makeup water requirements (e.g., 660 m^3/h). A cost effective way to remove suspended material from cooling water is to use a settling pond(18). Solids accumulating in such a pond must be removed on a regular basis. This type of waste should not contain toxic substances, and therefore it would not have to be hauled to special disposal sites. However, as a precaution, separated material should be analyzed to determine whether it is indeed environmentally benign.

Before agricultural effluents can be used as a source of cooling water, an acceptable method must be found to dispose of saline blowdown. As Figure 1 indicates, ponding and subsurface injection are two possible disposal options. Using the first option, blowdown would be discharged to an evaporation pond where the final waste product requiring disposal would be solids composed mainly of salts. A 50-MW power plant that has a cooling tower discharging 90 m^3/h of blowdown with 20,000 mg/l TDS would yield in excess of 1.0×10^7 kg of solids annually that ultimately must be removed from an evaporation pond. The primary disadvantage with this method of disposal is the land requirement of the pond. In the case above, nearly 40 ha would be needed to sustain an evaporation rate that is greater than the inflow of blowdown. In the Imperial Valley it would be difficult to site a pond of that size without removing agricultural lands from production. Under present waste-disposal regulations in California(17), evaporites from ponds would probably have to be hauled to a hazardous waste disposal site. Moreover, evaporation ponds would eventually have to be abandoned in such a way that subsequent environmental problems will not develop (e.g., leaching of salts to ground waters).

Subsurface injection of blowdown seems to be the most viable alternative to evaporation ponds. With subsurface disposal, blowdown would be injected through a well to an aquifer or aquifers that are within a geothermal reservoir or that are otherwise isolated from aquifers containing potable water. Blowdown may have to be filtered to remove suspended solids that could damage a receiving aquifer. Of special concern, though, are sulfate precipitates that could be formed within a geothermal reservoir when blowdown, which has a high concentration of dissolved sulfate, mixes with geothermal fluids containing Ba^{++} and Ca^{++}. The severity of solids plugging in reservoirs will vary according to the geohydrologic characteristics of the reservoirs as well as the chemistry of both the injection and geothermal fluids. To prevent the formation of precipitates, it would be necessary to either chemically bind sulfate so that it would not react with reservoir fluids or remove sulfate at the surface. If these options are impractical, it might be possible to inject blowdown in an aquifer that contains less reactive fluids. Further work is needed on all of the possible disposal methods.

The sole source of makeup water for cooling towers supporting flashed-steam power plants will be steam condensate. Subsurface injection is currently the preferred method of disposing blowdown from such cooling towers. If difficulties were encountered with injection, discharge of blowdown to agricultural drains and irrigation canals might be possible if toxic substances such as boron and ammonia were not present at elevated levels. To determine whether disposal to surface waters is indeed a feasible alternative, we used available data to calculate the potential concentrations of those chemicals in blowdown. Ammonia (un-ionized) is toxic to fish at low concentrations (a recommended maximum concentration is 0.02 mg/l)(19). Ammonia is present in geothermal fluids at concentrations of up to 35 mg/kg of fluid. A 50-MW flashed-steam facility in the Salton Sea resource area requiring 2.0 x 10^6 kg/h of geothermal fluids would produce 70 kg/h of NH_3. Data on NH_3 at power plant units 7 and 8 at The Geysers(20) indicate that 85% of the NH_3 is emitted to the atmosphere via cooling towers; the remaining 15% is discharged in blowdown. If we assume the same partitioning in the flashed-steam facility, the resulting blowdown discharged to an agricultural drain would contain 166 mg/l of total NH_3. The concentration of un-ionized NH_3 would be approximately 0.13 mg/l at pH 6.0 and 30^0C(21). A 50-MW power plant requiring 6.5 x 10^6 kg/h of lower temperature geothermal fluids containing 4.5 mg/kg of NH_3 would produce a blowdown containing 0.03 mg/l at the same pH and temperature. In both cases the NH_3 concentrations would have to be reduced to ensure that toxic effects to aquatic organisms do not occur.

Dissolved NH_3 would actually be a benefit when present in condensate discharged to an irrigation canal because the NH_3 would serve as a liquid fertilizer. Boron, however, must be kept below 5 mg/l to protect semi-tolerant crops such as tomatoes, wheat, and cotton(22). Data on the chemistry of condensate produced from an experimental geothermal facility located in the Salton Sea resource area(23) show that boron is present in condensate at about 5 mg/l. The total dissolved solids of the condensate was as high as 575 mg/l, but irrigation water in the valley typically contains over 900 mg/l. Because condensate seems to be suitable for irrigation, it would be feasible to use irrigation water for power-plant cooling and to replace it with an equivalent volume of condensate. Blowdown from the cooling system would be kept below 4,000 mg/l TDS and then discharged to an agricultural drain. An ion-exchange process could be used to remove boron selectively from condensate if it were necessary to reduce boron to below 5 mg/l before discharging condensate to a canal(24). This method of treatment must be tested on condensate from a geothermal facility.

One advantage of exchanging irrigation water for condensate as a source of cooling water is the elimination of boron emissions from a cooling tower. At The Geysers, damage to vegetation near some towers is attributed to boron emitted as cooling tower drift(25). Crops in fields that are adjacent to towers in the valley could also be damaged by drift containing boron. The boron emission rate from a tower will depend on the concentration of boron in the cooling water, the circulation rate of cooling water in the tower, and the effectiveness of drift eliminators. A cooling system supporting a 50-MW flashed-steam power plant in the Salton Sea resource would emit about 77 kg boron/yr, based on a circulation rate of 17,600 m^3/h, makeup water with 5 mg/l of boron, five cycles of evaporative concentration, and a drift rate of 0.002% of the system's circulating flow. With less efficient elimination of drift, more boron would be emitted. Maximum boron emissions from the cooling tower supporting a 53-MW facility (i.e., unit 11) at The Geysers, by comparison, are estimated at 2,273 kg/yr(20). Stressed vegetation has been detected in the vicinity of that generating facility(25). Even though our calculated emission rate for the hypothetical case is considerably below that estimated for The Geysers facility, an effort should still be made to minimize boron emissions. The key design parameter will be the drift-elimination rate. A 100-MW power plant, for example, would emit 1,540 kg/yr if the drift rate were 0.02%. Therefore, it seems prudent to design the initial cooling towers so that their drift rates are not greater than 0.002% particularly for power plants in the Salton Sea resource area where the geothermal fluids have the highest level of boron. Furthermore, field studies should be implemented to determine whether crops grown adjacent to cooling towers are adversely affected by drift emissions.

CONCLUSIONS AND RECOMMENDATIONS

The generation of electricity from the hot-water geothermal resources of the Imperial Valley will involve the use of energy technologies that are still at the demonstration stage of development. To ensure that adverse impacts are not caused by the operation of the initial power plants in the valley, it will be necessary to implement environmental control measures. In this paper we have addressed some of the control needs associated with accidental releases of geothermal fluids, the production of liquid and solid wastes, and the use of alternative water supplies for power plant cooling.

Inadvertent spills of geothermal fluids are a special concern in the Imperial Valley because they could have serious impacts on irrigated lands. Accordingly, appropriate measures should be taken to prevent, limit, or contain spills. The simplest control option is to construct berms around places where releases are most likely to occur (e.g., wells and power plants). In order to limit the duration of a spill, it will be necessary to close flow valves shortly after a release is detected. Pressure-activated alarms would be one possible way of alerting plant operators of a spill so that they can respond in a timely fashion. Until we have acquired more experience from the actual operation of geothermal facilities, it will be difficult to judge the adequacy of such control measures. A valuable post-operational study regarding accidental fluid releases would be to monitor the frequency and magnitude of spills and to determine the causes of each release. Data obtained from this type of study could be used to improve methods of preventing or limiting spills.

Spent geothermal fluids constitute the largest source of waste from geothermal facilities. The preferred method of disposal for these fluids is subsurface injection. For the low salinity fluids of the East Mesa and Heber resource areas, injection appears to be technically feasible. However, at the Salton Sea resource area, significant amounts of suspended solids must be removed from residual fluids before they can be injected into a geothermal reservoir. We estimate that the operation of a 50-MW power plant would result in the separation of up to 3.9×10^6 kg/yr of solids from spent geothermal fluids. Separated solids would have to be removed to a waste disposal site that is certified to receive wastes containing toxic substances. The removal of scale from pipelines and power plant components represents the second largest source of solid waste. To reduce the quantity of scale that has to be disposed and to improve the reliability of power plant operation, it will be necessary to inhibit the formation of scale. This should be the subject of continuing research. Solid waste from the control of hydrogen sulfide, on the other hand, may not represent a disposal problem, provided that a commercial by-product such as fertilizer can be produced.

The most important environmental concerns related to the use of cooling water involve the disposal of blowdown and emissions of drift from cooling towers that support flashed-steam facilities in the Salton Sea resource area. Blowdown derived from steam condensate would contain ammonia that can be toxic to fish, while drift emitted from a tower would contain boron that is potentially harmful to crops. We recommend that cooling towers be designed to minimize emissions of drift to prevent possible boron-related damage to crops. The effects of drift on crops grown near cooling should be the subject of post-operational studies. Blowdown containing ammonia will probably be disposed by subsurface injection to avoid toxic effects to aquatic organisms. However, it may also be possible to discharge condensate to an irrigation canal and in its place use irrigation water for cooling. The advantage of this exchange of cooling waters is the elimination of drift emissions containing boron. In addition, the ammonia in the condensate would act as a fertilizer. The condensate may have to be treated to remove boron in order to protect sensitive crops. Other contaminants may have to be controlled as well. Further work is needed to define the suitability of condensate as a source of irrigation water.

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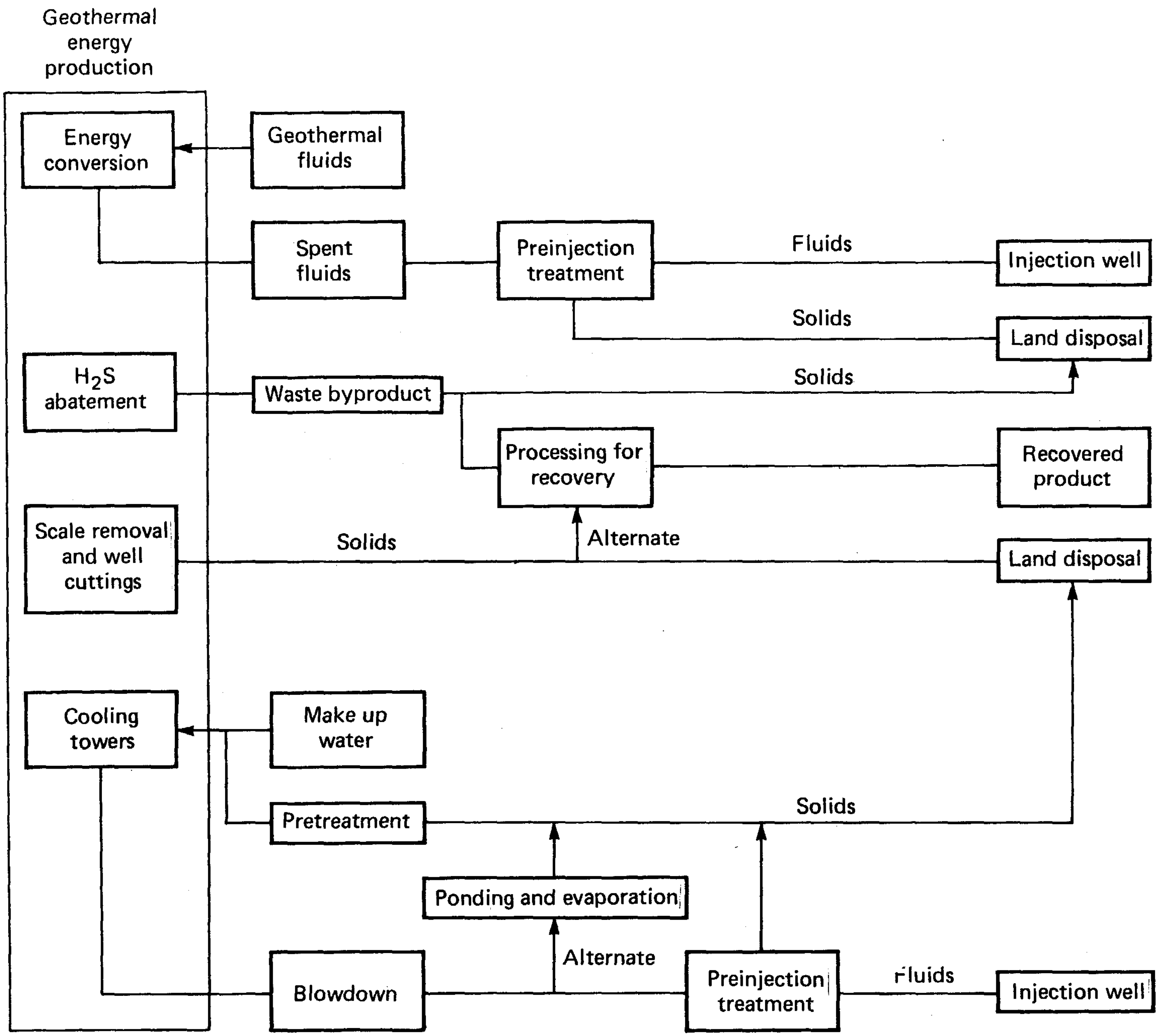
Figure Caption

Fig. 1. Methods of disposing liquid and solid wastes from geothermal facilities that use the hot-water geothermal resources in California's Imperial Valley.


Geothermal energy production
Energy conversion
Geothermal fluids
Spent fluids
Preinjection treatment
Fluids
Injection well
Solids
Land disposal
H_2S abatement
Waste byproduct
Solids
Processing for recovery
Recovered product
Scale removal and well cuttings
Solids
Alternate
Land disposal
Cooling towers
Make up water
Pretreatment
Solids
Ponding and evaporation
Alternate
Blowdown
Preinjection treatment
Fluids
Injection well